

Contamination Examples and Lessons from low Earth orbit experiments and operational hardware

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Flight experiments flown on the Space Shuttle, the International Space Station, Mir, Skylab, and free flyers such as the Long Duration Exposure Facility, the European Retrievable Carrier, and the EFFU, provide multiple opportunities for the investigation of molecular contamination effects. Retrieved hardware from the Solar Maximum Mission satellite, Mir, and the Hubble Space Telescope has also provided the means gaining insight into contamination processes.

Images from the above mentioned hardware show contamination effects due to materials processing, hardware storage, pre-flight cleaning, as well as on-orbit events such as outgassing, mechanical failure of hardware in close proximity, impacts from man-made debris, and changes due to natural environment factors.. Contamination effects include significant changes to thermal and electrical properties of thermal control surfaces, optics, and power systems.

Data from several flights has been used to develop a rudimentary estimate of asymptotic values for absorptance changes due to long-term solar exposure (4000-6000 Equivalent Sun Hours) of silicone-based molecular contamination deposits of varying thickness.

Recommendations and suggestions for processing changes and constraints based on the on-orbit observed results will be presented.

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Introduction

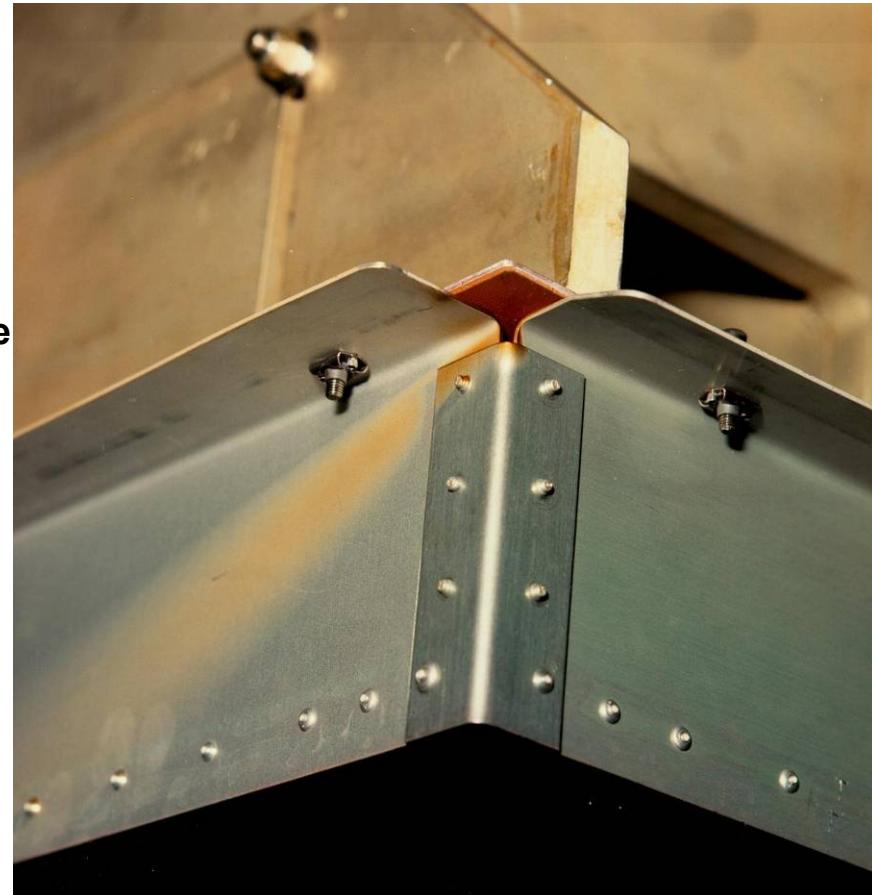
- **Examples of contamination effects on flight hardware.**
- **LDEF**
- **Mir**
- **Solar Max**
- **ISS**
- **Variety of mechanisms and events**
 - Pre-flight storage
 - Materials selection
 - Assembly procedures
 - “workmanship”
- **On-orbit manifestations of pre-flight events or processes**
- **On-orbit events and processes**

On-orbit induced changes to pre-flight contamination

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- Prior to launch, trays were stored with aluminum lids that had silicone rubber gaskets along the tray perimeters
- The gaskets had a line-of-sight view to the exterior of the experiment trays
- Space Environment “fixed” the contamination to the tray surface
 - Volatile contaminants condensed on surface
 - In this case, AO oxidized silicones to SiO₂
 - Solar UV caused chain scission and cross-linking in polymers that resulted in browning
- Non-uniformity of discoloration is due to variation in thickness and AO and UV exposures



NASA Image

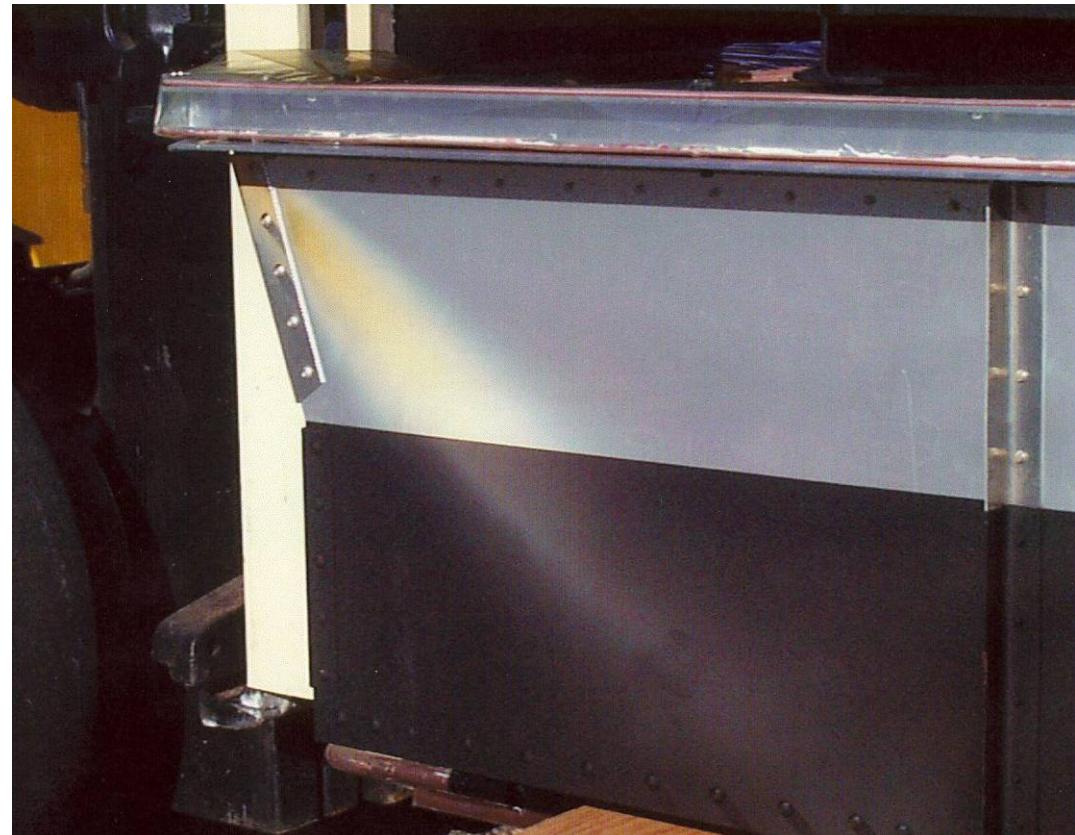
Depth-composition profiles on Contaminates

- During de-integration, large plumes of contamination were noticed on experiment tray panels
- Hypothesized that the plumes consisted of a range of thicknesses that corresponded to a range of environmental exposures

“Comparison of Spacecraft Contamination Models with Well-Defined Flight Experiment”
NASA Contract NAS8-40581

“Study of Long Duration Exposure Facility Contaminated Chromic-Acid-Anodized Surfaces”

JSR vol.38 no.4, pp 569-577.



NASA Image

Results of contamination event on Mir

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Structural Technology

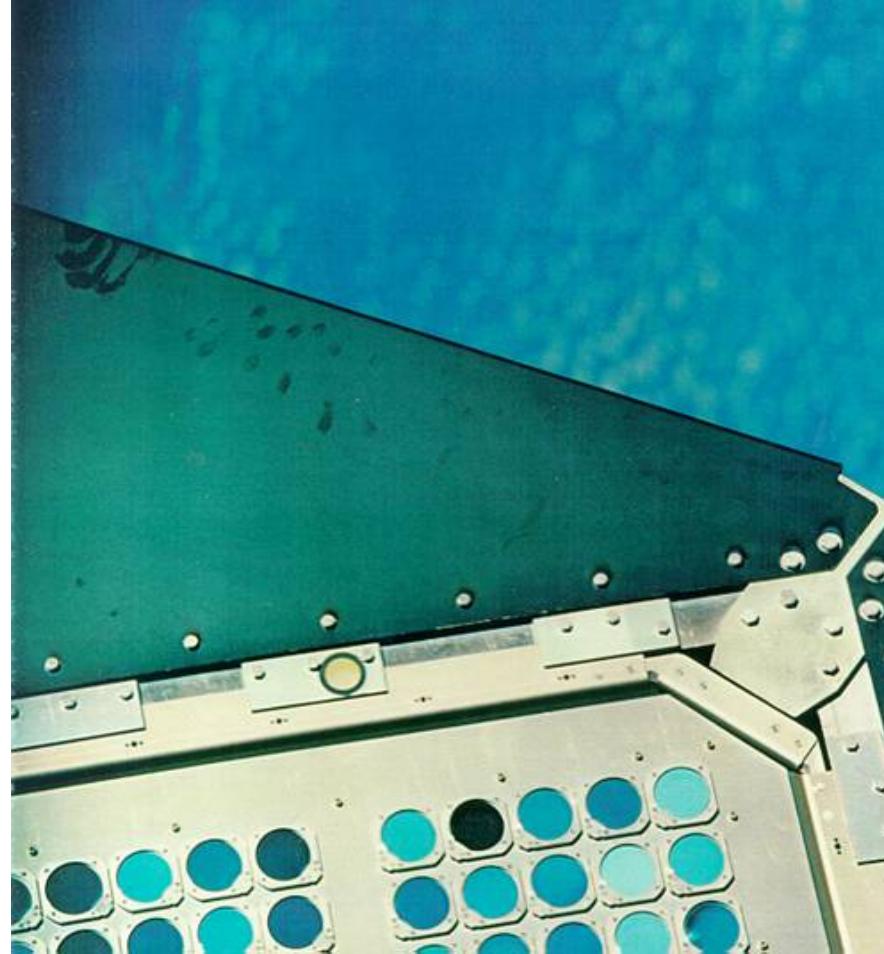
- “Black-light” image of contamination on POSA II



NASA Image

On-Orbit Effect due to Pre-flight handling

- **Fingerprints show up clearly on the anodized hardware**
- **Significant change in optical properties at location of contact**
- **These issues could be critical for small spacecraft where thermal control areas are limited**



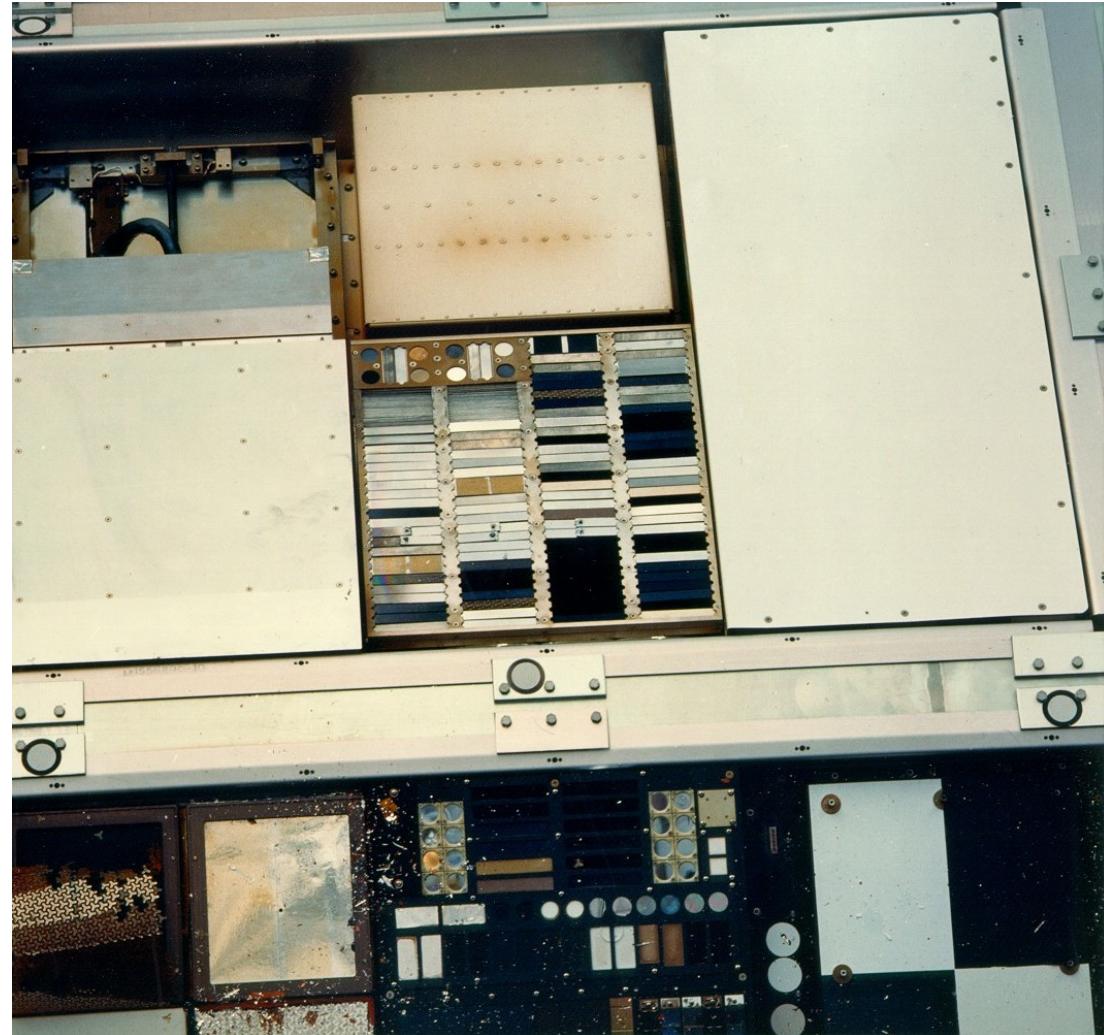
NASA Image

On-Orbit Events and Processes

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- Two contamination features are present
- Debris from one experiment has migrated onto an adjacent experiment (blown off during Re-entry)
- Darkening around fastener locations (similar effect on HST)

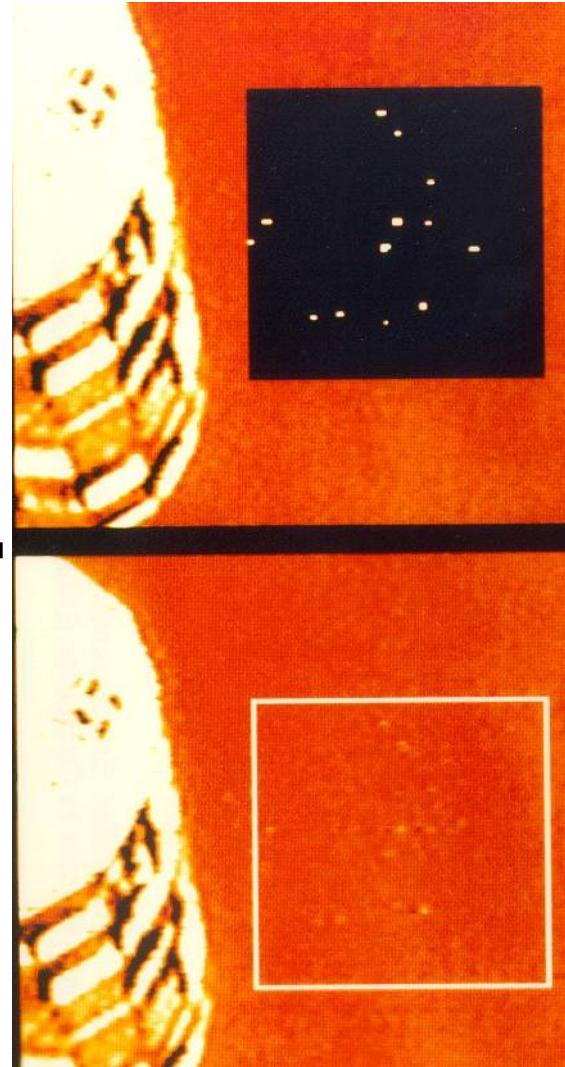


NASA Image

Debris Cloud in LDEF Wake

- **Mechanism must explain particle migration from ram side of LDEF**
- **Debris are aluminum foil from failed thin film**

←
Direction
Of Motion



Multiple frames
averaged

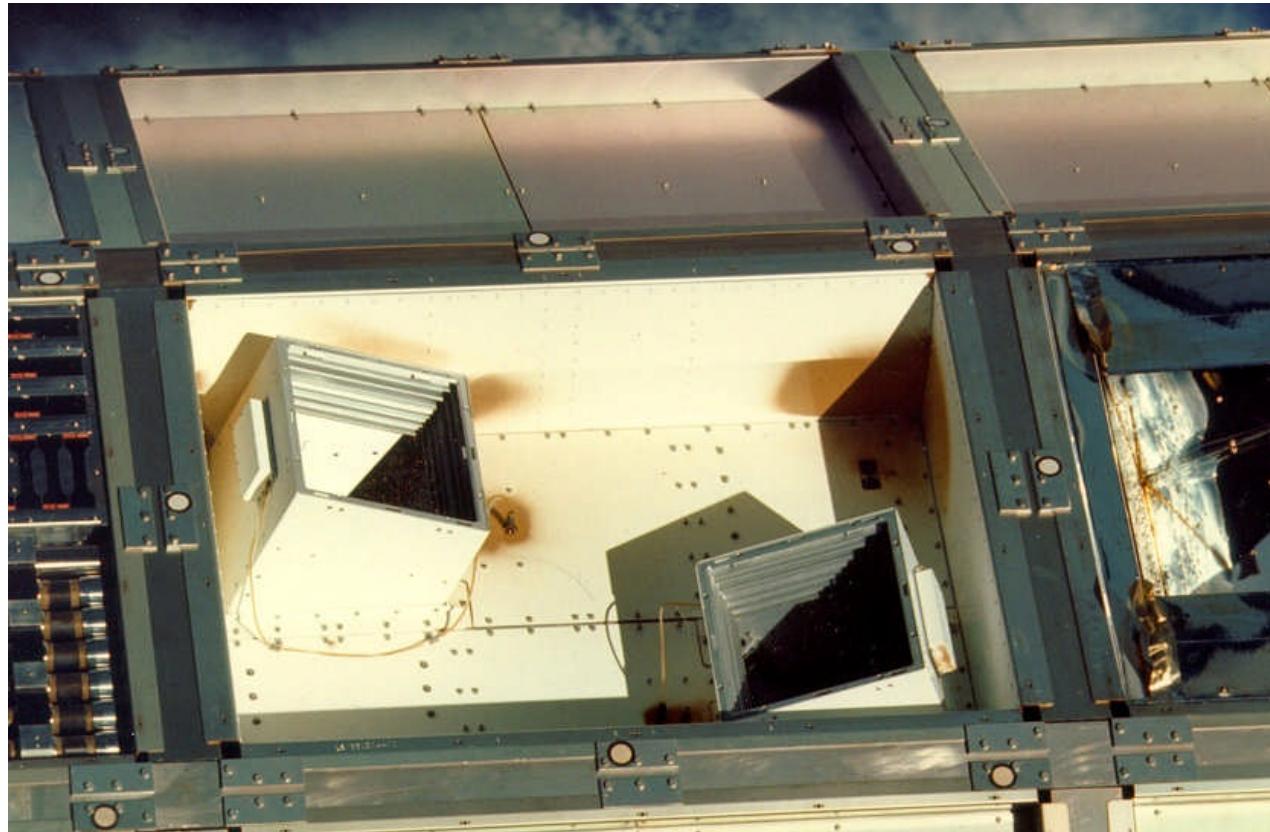
Single video
frame

On-Orbit processes

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- Material depositions appear to be influenced by electrostatic effects, also thermal cycling



NASA Image

Solar Exposure induced changes

- Not every observed discoloration is due to contamination

Adhesive under FEP
layer darkened by
~11000 Equivalent
Sun Hours (ESH)
of direct solar exposure

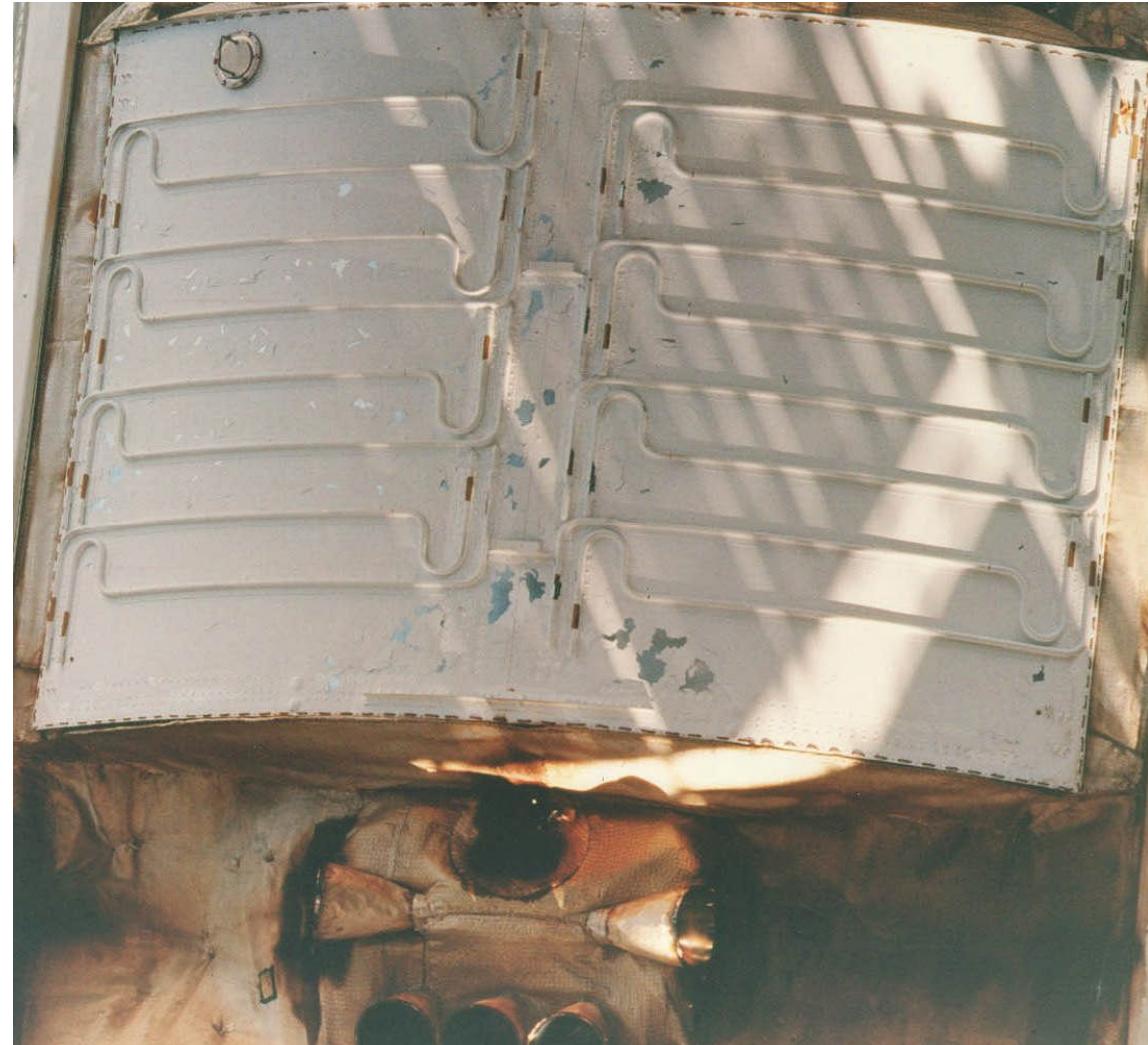
Adhesive “bled-through”
cracks in silver-inconel
layer created
during application of
film to substrate



NASA Image

MIR “Contamination” Examples

- **Failure of paint adhesion**
- **Thruster plume contamination**

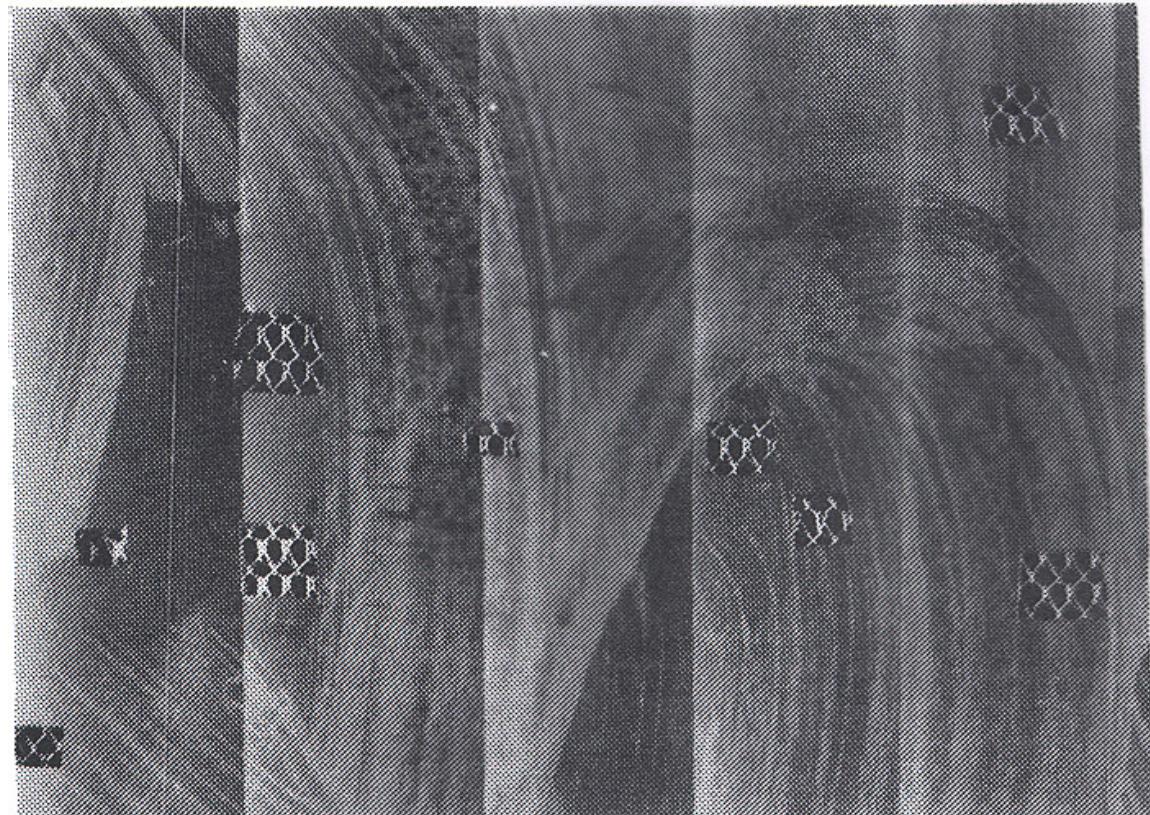


Pre-Flight “Cleaning”

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- Solar Max Kapton surface “wiped down” pre-flight
- On-orbit UV exposure induced changes



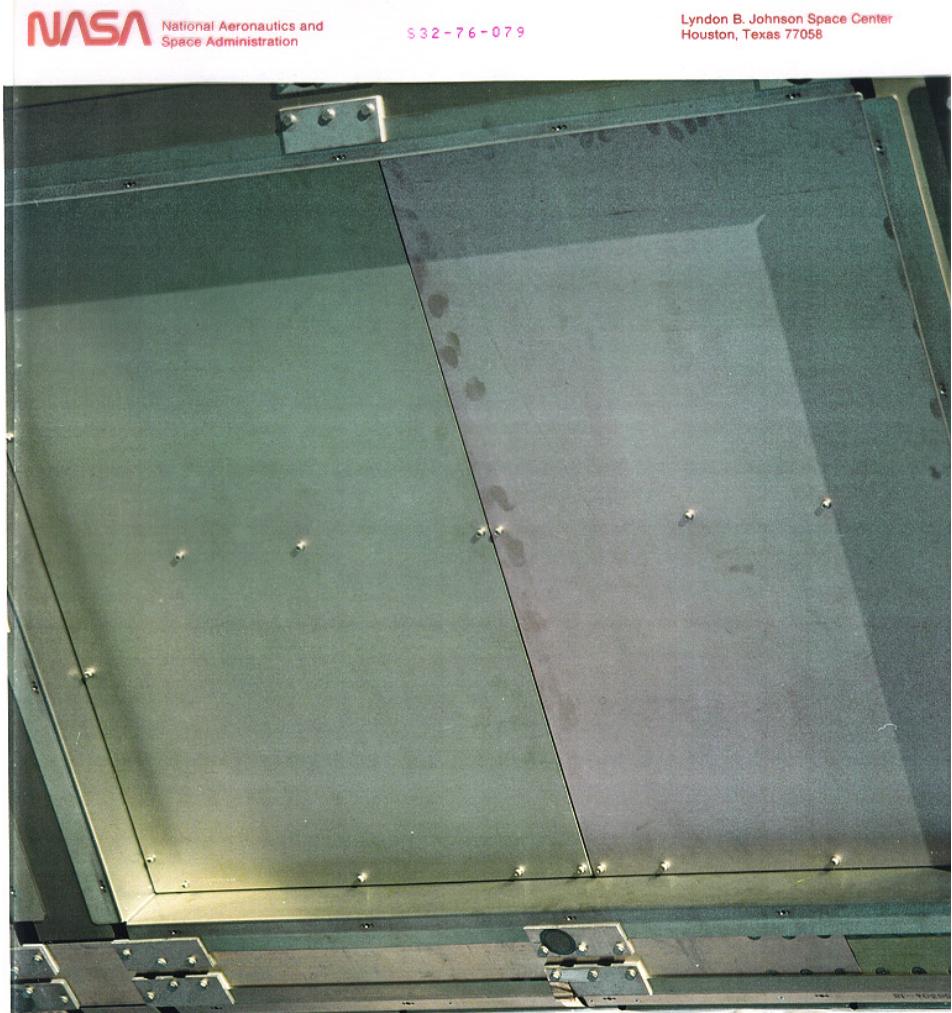
NASA Image

Assembly Procedure Issues

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- **Thermal control panel installation shows use of un-gloved hands**



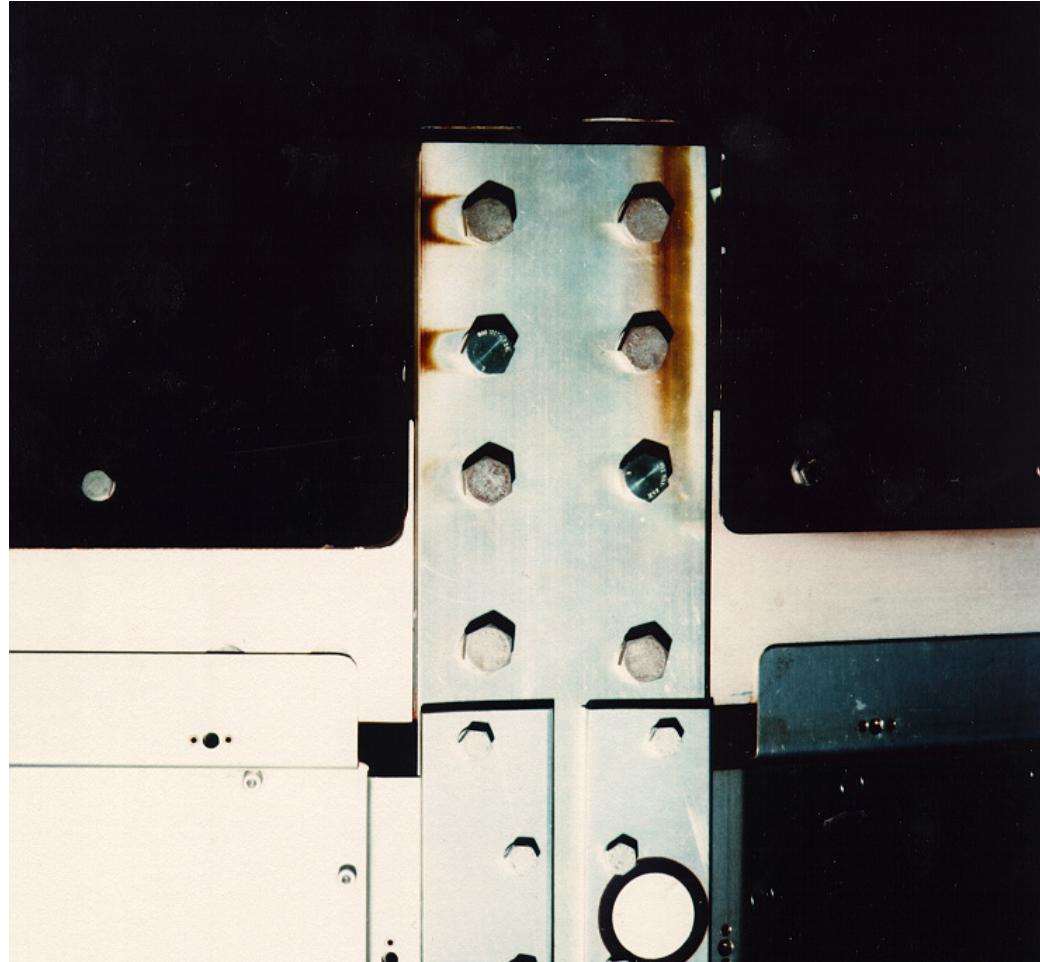
NASA National Aeronautics and Space Administration

532-76-079

Lyndon B. Johnson Space Center
Houston, Texas 77058

Post-deposition discoloration of outgassed materials

- Venting from LDEF interior is source of contaminant
- Details of the mechanism are subtle
- Pattern depends on at least 4 time-varying factors
 - Outgassing
 - Temperature
 - Atomic oxygen
 - Solar Exposure



NASA Image

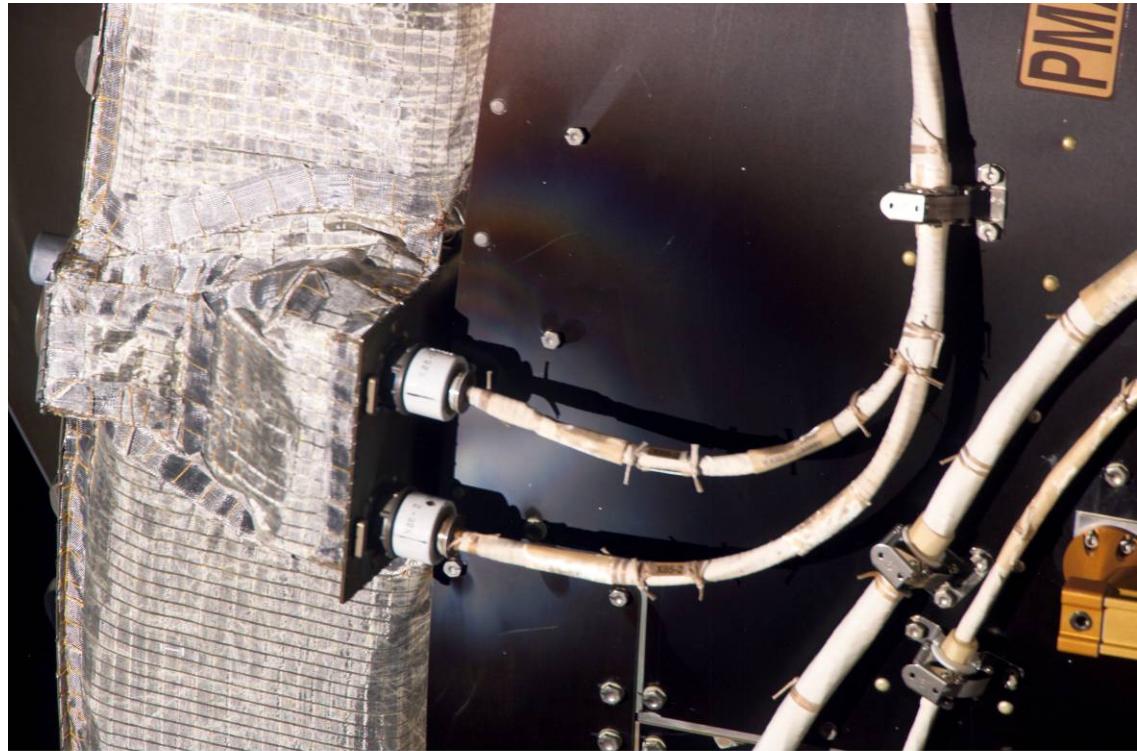
Post-deposition discoloration of outgassed materials

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Pressurized Mating Adaptor-3 with Russian cables

- Either vent path or outgassing from cable connectors
- In general, contamination on ISS appears to be localized
- Material selection and stringent outgassing reqs.

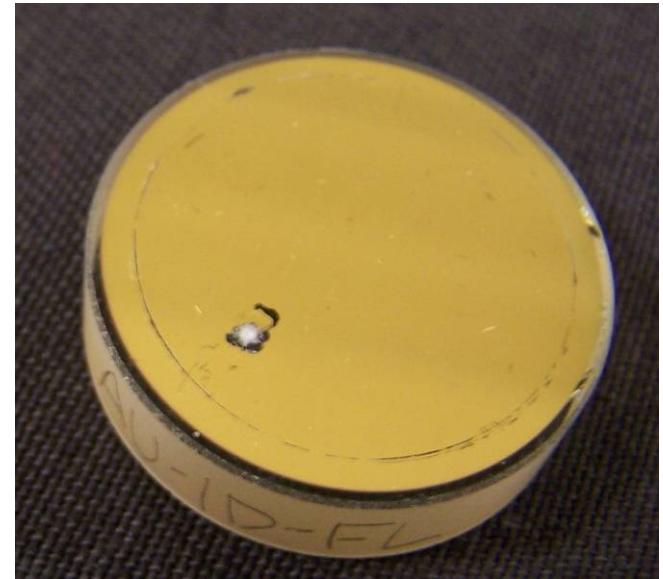


NASA Image

MISSE-2 Contamination Levels

- **MISSE-2 Optical Witness Samples**

- Four years on orbit
- Ram side ~4 nm contaminant
- Wake side ~44 to 50 nm
- Mostly SiO_2
- Ellipsometry, ESCA in agreement with model predictions



Gold mirror with MMOD impact

NASA Image

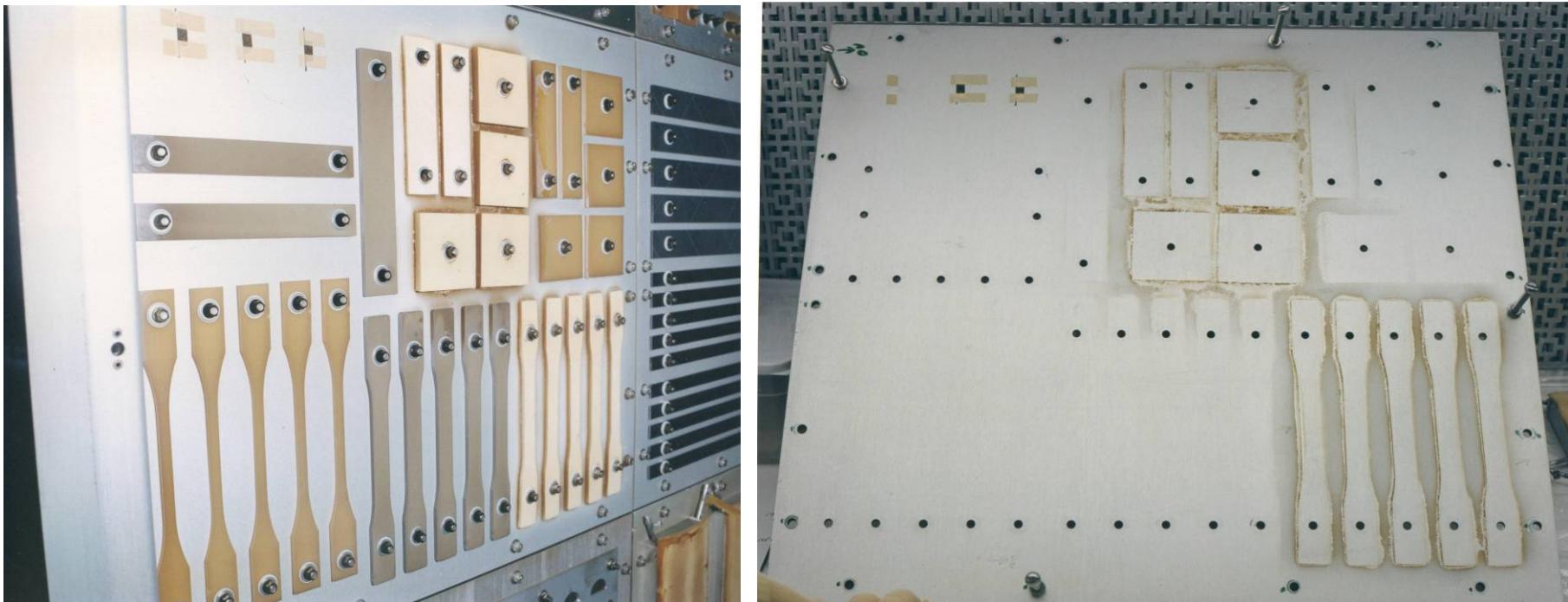
These levels of contamination may be significant for optical surfaces

Long-term Outgassing On-orbit

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- **contamination example from LDEF AO171 experiment**
- **Variety of molecular deposits**
 - Silicone, Fluorocarbon, Organic



NASA Images

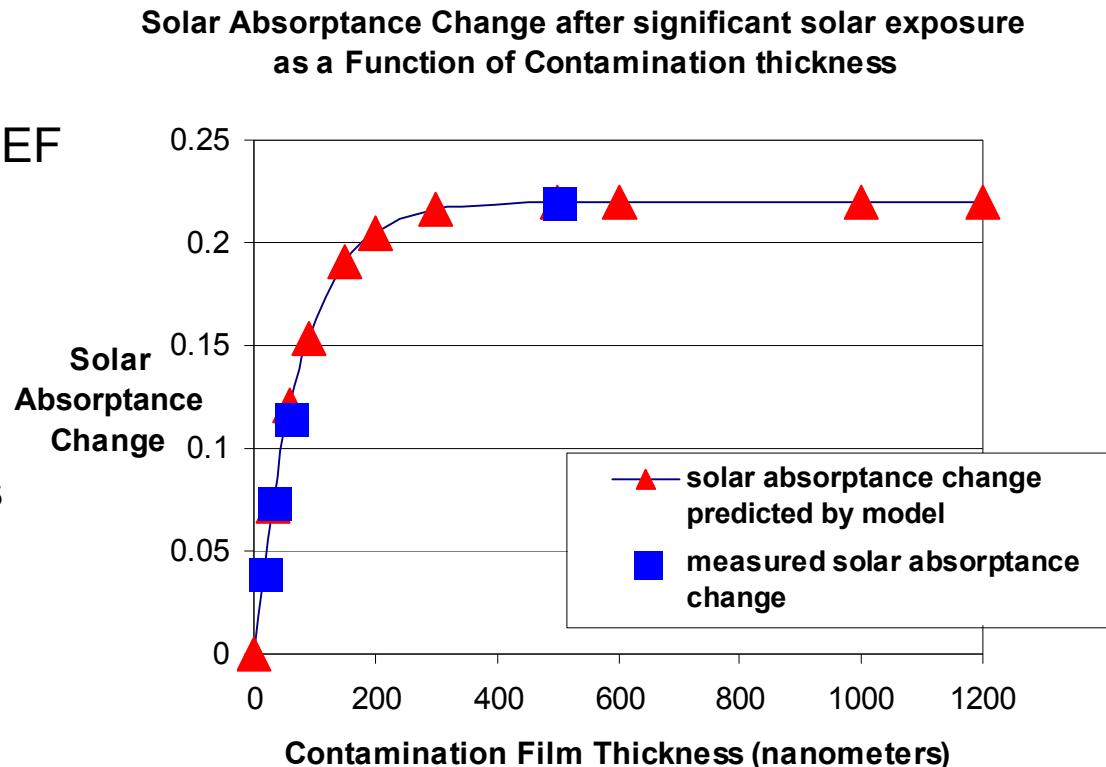
Outgassing-induced optical property changes on AO171

- RTV 511 material samples from AO171 on LDEF
- Samples cut pre-flight, after bakeout

Solar absorptance	deposition thickness (mil) (control)	solar absorptance change
0.35		0.00
0.41	0.4-0.65	0.06
0.43	0.4-0.45	0.08
0.48	1.5-1.85	0.13
0.48	0.8-1.2	0.13
0.50	1.5-2.0	0.15
0.50	0.85	0.15

Asymptotic absorptance change for silicones

- **Measured results from different flights**
- **Solar absorptance change is for long term (several thousand Equivalent Sun Hours) solar exposure**



Asymptotic value from LDEF

Two measurements from
Geosynchronous satellite
(AIAA-87-1571)

Solar Max measurements

Summary

- **Differences in solar absorptance change examples due to details of exposure history**
- **Effects of workmanship and pre-flight handling will become more significant for smaller structures**
- **Optical property changes due to contamination can be large**
 - Two examples presented show $\Delta\alpha$ greater than 0.15
 - Maximum changes do require significant exposure to the sun
 - Large changes can occur in very thin contamination layers
- **Effects which produce significant on-orbit changes are often not observable through pre-flight visible inspections**
 - Black light inspection may reveal handprints, tape residue, etc.